



Jet Propulsion Laboratory
California Institute of Technology

Aerosol profiling using radiometric and polarimetric spectral measurements in the O₂ A-band

Myungje Choi^{1*}, Stanley P. Sander¹, Thomas J. Pongetti¹, Jonathan H. Jiang¹, Robert J. D. Spurr², Dejian Fu^{1*}

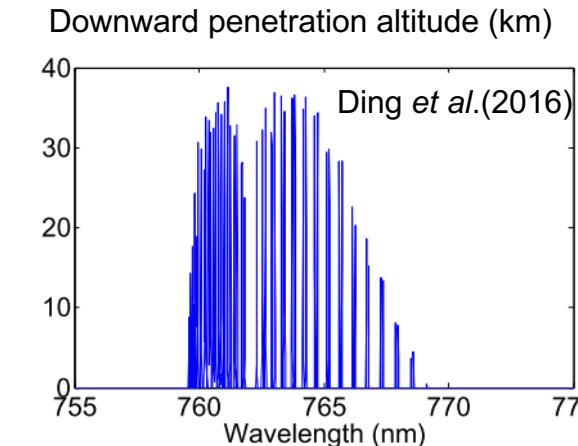
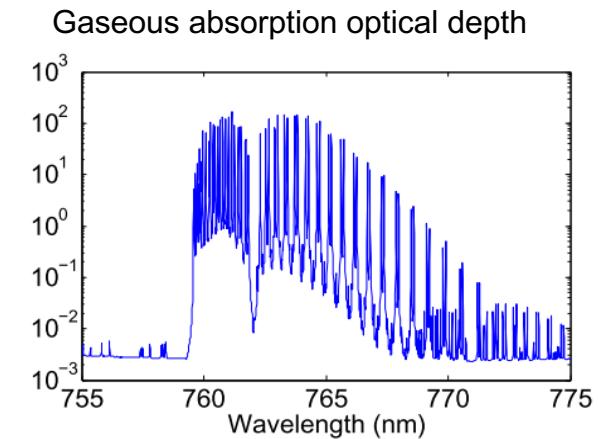
¹ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, USA

² RT Solutions Inc., Cambridge, MA, 02138, USA

* Points of Contact: myungje.choi@jpl.nasa.gov
dejian.fu@jpl.nasa.gov

Aerosol vertical profile retrievals using O₂ A-band

- Measurement approach to help in obtaining aerosol vertical distribution information
 - High spectral resolution
 - Polarization
 - Multi-viewing angle
- Current state of measurement has been focused on radiance-only.
 - Radiometers: MERIS, POLDER, EPIC, 3MI, MAIA
 - Spectrometers: GOME-2, SCIAMACHY, TANSO-FTS, OCO-2, CarbonSpec, TROPOMI, OCI
- Joint radiance/polarization measurement can significantly increase information contents
 - Stam *et al.*(1999), Boesche *et al.*(2008), Wang *et al.*(2014), Ding *et al.*(2016)
 - Lack of analyses quantifying the impact of spectral resolution, signal-to-noise ratio on aerosol profiling

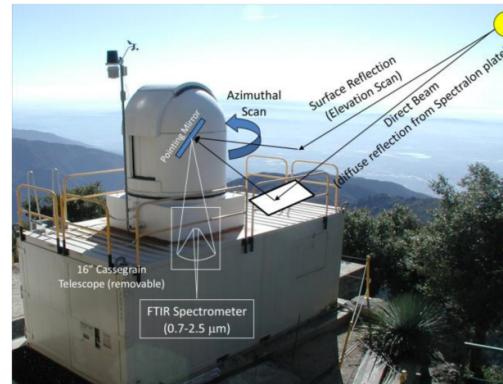


Objectives of this study

- Develop Observing System Simulation Experiment (OSSE) framework for aerosol vertical distribution retrievals using O₂ NIR bands (radiance/polarization)
- Information content analysis for aerosol profiling in the planetary boundary layer over LA basin, when employing high spectral resolution, joint radiometric/polarimetric measurement.
- CLASR-FTS
 - Extend measurements to O₂ A-band
 - Linear polarization measurements with a high spectral resolution
- To inform the requirement of future mission

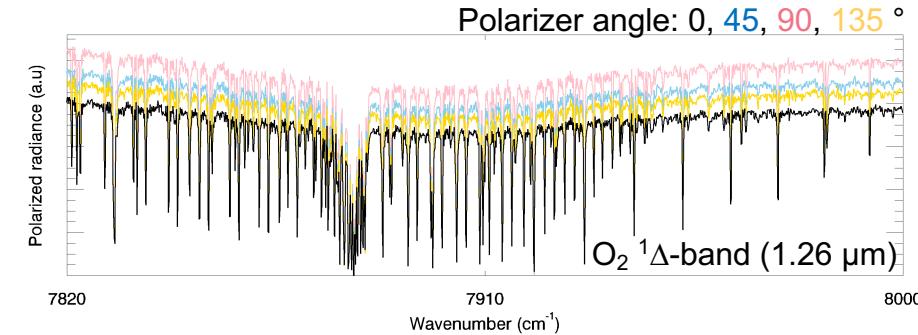
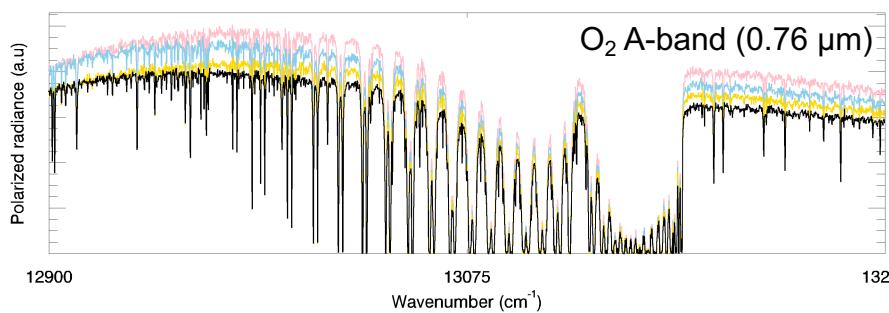
CLARS-FTS

Jet Propulsion Laboratory (JPL)'s
California Laboratory for Atmospheric Remote Sensing (CLARS) - Fourier transform spectrometer (FTS)



Wong et al. (2015)
Fu et al. (2014)
Zeng et al. (2018)

Sample spectrum from CLARS-FTS polarized radiance measurement



Observing System Simulation Experiment (OSSE) framework

Climatology over LA basin

- Constraint information of aerosol and surface
- Seasonal/monthly ground-based/satellite products

RT simulation

- VLIDORT 2.7 (Spurr 2016)
 - Total radiance (I)
 - Linear polarization (Q, U)
 - Jacobian ($\frac{\partial y}{\partial x}$)

Simulated observation

- Instrument model
 - Instrument line shape function
 - Signal-to-noise ratio (SNR)
- Calibration uncertainty

Information contents and retrieval error

- Optimal estimation method (Rodgers 2000).
 - Degree of freedom for signal (DFS)
 - Posteriori error (or retrieval error)
 - Sensitivity to calibration uncertainty

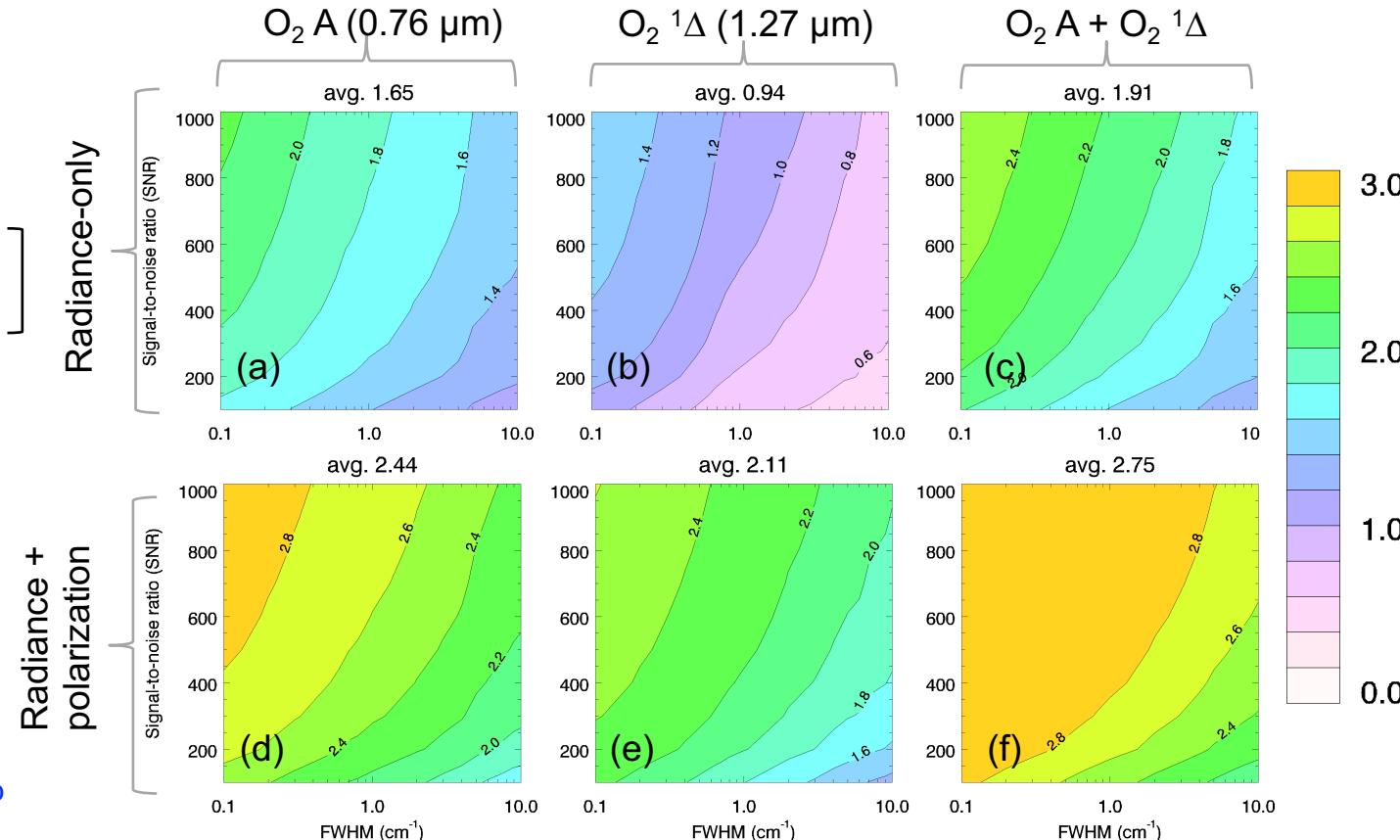
Information contents quantification

DFS of aerosol profiling estimated for CLARS-FTS

Mean of 50 aerosol loading
scenarios

AOD: 0.3, 1.0
PH: 0.2, 0.6, 1.0, 1.5, 2.0 km
HW: 0.2, 0.6, 1.0, 1.5, 2.0 km

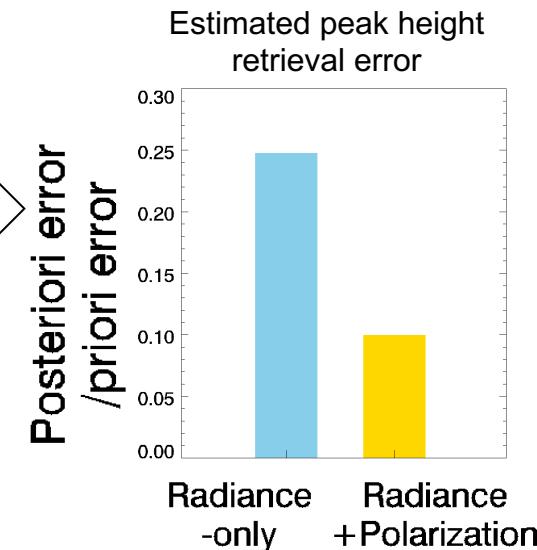
- (a) A-band > (b) $^1\Delta$ -band
 - higher aerosol signal + lower surface reflectance in A-band
 - Insignificant increase (DFS~0.3) in (c) joint bands then (a) A-band only
- Polarization adds DFS~0.8 to aerosol profiling



Improved information contents using polarization (CLARS-FTS; O₂A)

Retrieval quantities (no. pars)		Radiance-only	Radiance +polarization
Aerosol profiling	AOD (1)	★★	★★★★★
	Peak height (1)	★★★★★	★★★★★
	Half width (1)	★★★	★★★★★
Aerosol microphysical properties	Size dist. (5)	★★	★★★★★
	Refractive indices (4)	★★	★★★★★
Surface reflectance	BRDF (3)	★	★

(FWHM 1 cm⁻¹; SNR 300)



- Polarization adds more information contents to aerosol profiling and microphysical properties.
- Adding polarization results in significantly reduced retrieval error of Peak height, which has already matured DFS using radiance-only.

Information contents of O₂ A-band (CLARS vs Satellite)

DFS of vertical distribution (AOD, Peak height, half width)	CLARS	Satellite		
	VZA 83°	Nadir	3 angles	9 angles (MAIA-like)
	High spectral resolution (FWHM 1 cm ⁻¹ ; SNR 300)			Band-averaged (15 nm; SNR 300)
Radiance	1.63	0.86	1.66	0.43
Radiance + Polarization	2.42	1.70	2.68	0.96

High spectral resolution measurement approach

DFS~0.7 diff.

- CLARS single viewing geometry ≈ satellite 3 viewing angles (0, ±20°) > satellite nadir-only

Band-averaged O₂ A-band-only doesn't provide enough information for aerosol profiling even multi-angle and polarization is added.

- Combining with other spectral bands (e.g. UV, VIS, IR) can increase other aerosol properties (e.g. microphysical properties). Then aerosol profiling information can be increased.

Summary

Developed an algorithmic tool and performed OSSEs that quantify the information contents and retrieval uncertainties for both ground-based and LEO satellite viewing geometries across a suite of aerosol scenarios.

When combining spectrally resolved radiance and polarimetric measurements, the information contents of aerosol profiling (**~0.8** to 3 parameters) significantly increase while the retrieval uncertainties for both ground-based and LEO satellite measurements.

CLARS viewing geometry has more information of aerosol profiling (**~0.7** greater) than satellite-nadir viewing geometry, thus adding spectrally resolved polarization to CLARS-FTS is suitable for the testbed of future missions.

Next steps:

- Detail polarimetric calibration of CLARS-FTS
- Retrievals of aerosol vertical distribution using calibrated CLARS-FTS radiance/polarization spectra.
- Validation via independent measurements (Lidar, TROPOMI, etc.)

Thanks for your attention!

The authors thank to

Timothy J. Crawford, David J. Diner, Brian J. Drouin, Michael J. Garay,
Gerard Van Harten, Olga Kalashnikova, Keeyoon Sung, Feng Xu
for many helpful discussions.

This research was supported by the following programs

- FY2019-FY2020 Jet Propulsion Laboratory Strategic Initiative R&TD Task
 - NASA Earth Science Technology Office Directed R&TD Task

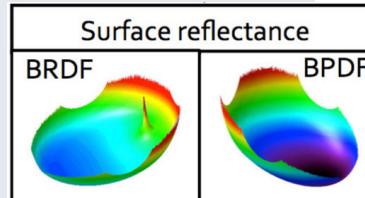
Aerosol/surface/gases climatology over LA basin

State vector $x = \{$

(each band) BRDF-isotropic, BRDF-volumetric, BRDF-geometric,
REFR-fine/coarse, REFL-f/c, PSD-radius-f/c, PSD-sigma-f/c, FMF,
AOD, Peak height, Half width,
Surface pressure, H₂O scale, Temperature shift

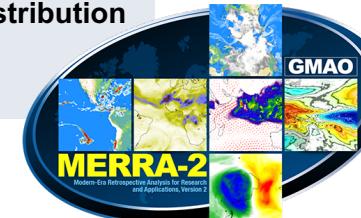
Surface BRDF/BPDF

- MODIS MAIAC
(Lyapustin *et al.*, 2018, AMT)
- POLDER GRASP
(Dubovik *et al.*, 2014, SPIE)
- Spectral relationship
from SCIAMACHY
(Tilstra *et al.*, 2017, JGR)



Pressure, Temperature, H₂O vertical distribution

- MERRA-2(Gelaro *et al.*, 2017, J. Clim)



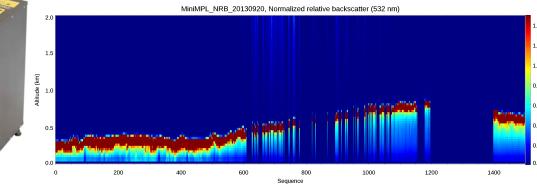
Aerosol microphysical properties

- AERONET over LA basin
(Holben *et al.*, 1998, RSE; Giles *et al.*, 2019, AMT)
- refractive indices, size distribution, AOD

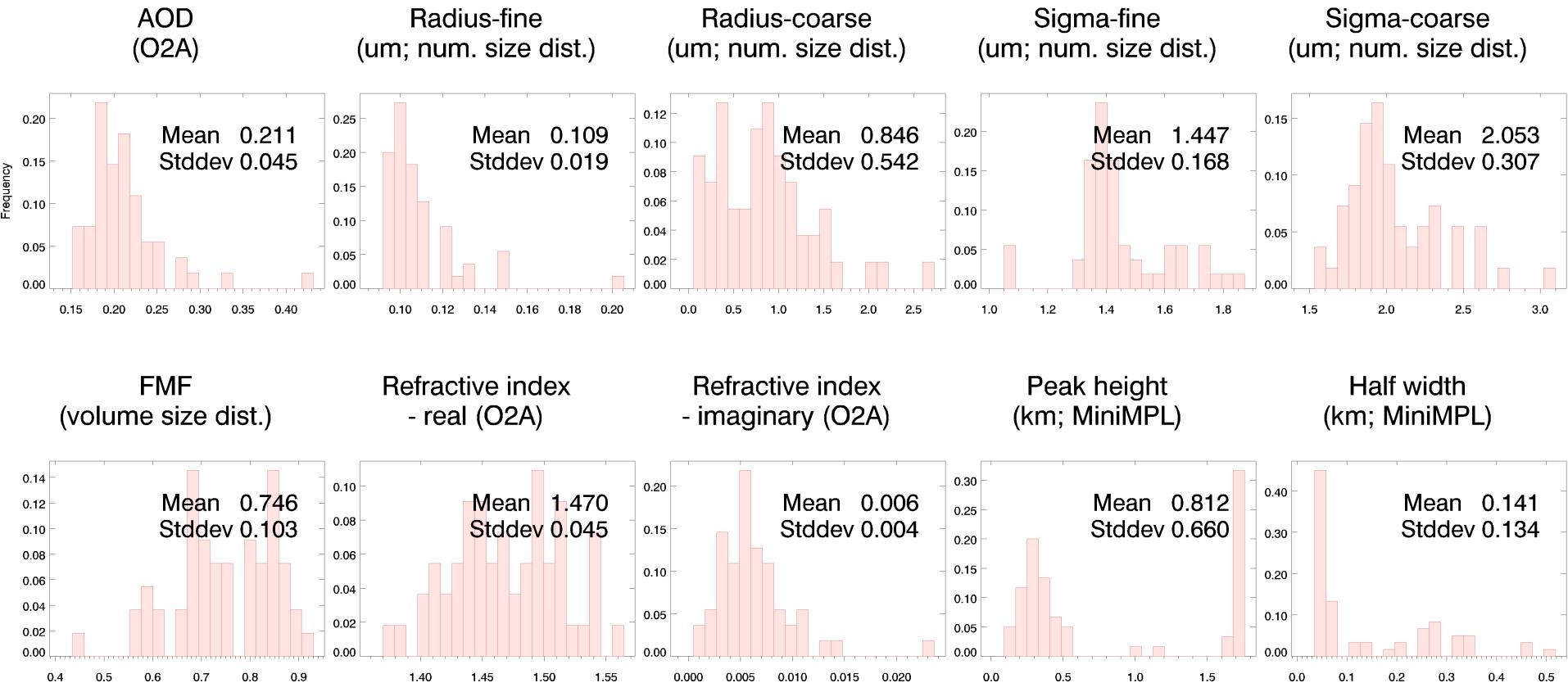


Aerosol vertical distribution

- Caltech MiniMPL
(Ware *et al.*, 2016, JGR)
- Peak height, half width



Climatological aerosol properties over LA basin (JJA)

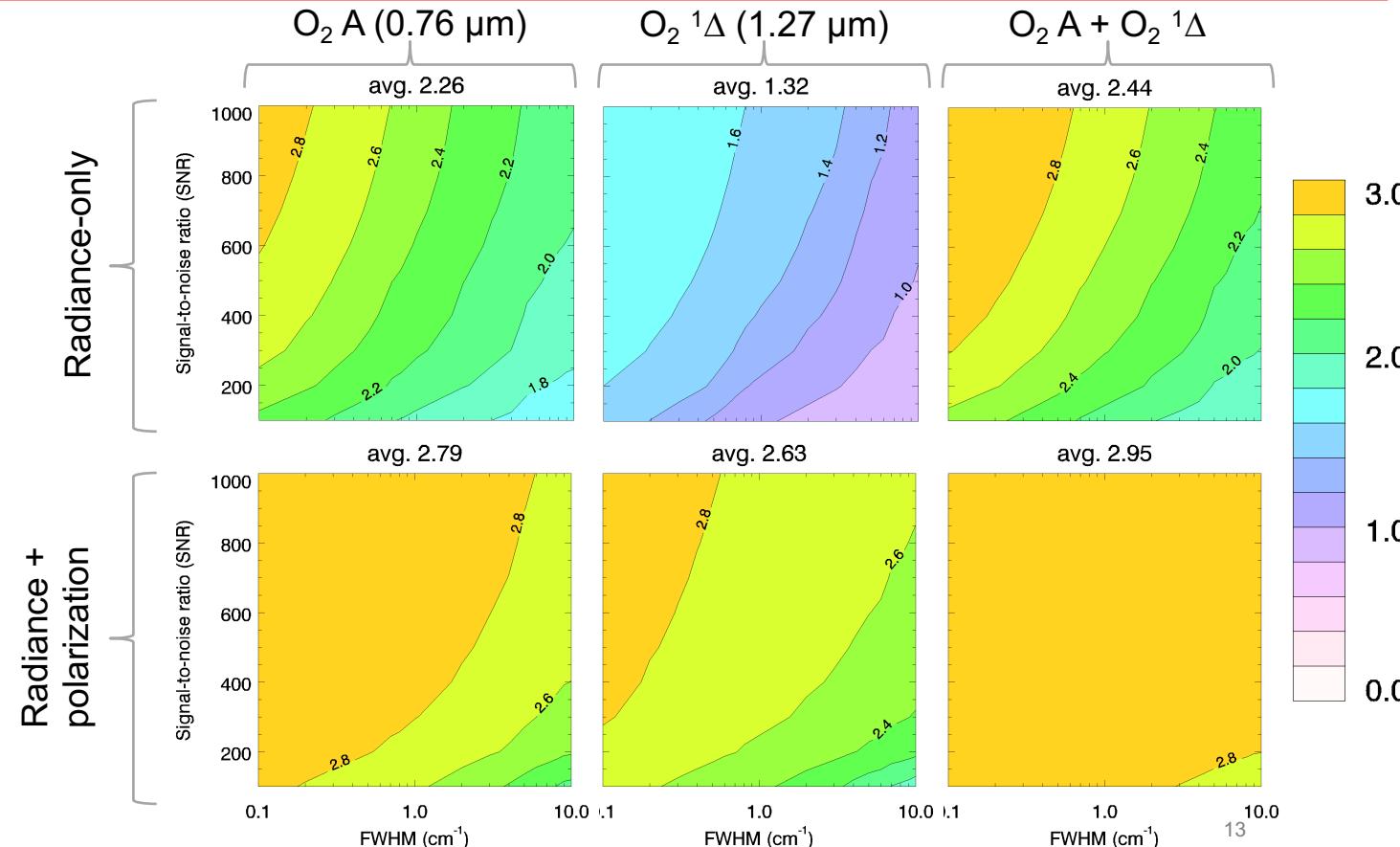


Information contents quantification

DFS of aerosol profiling estimated for CLARS-FTS

- AOD 0.3
- Peak height 0.6 km
- Half width 0.6 km

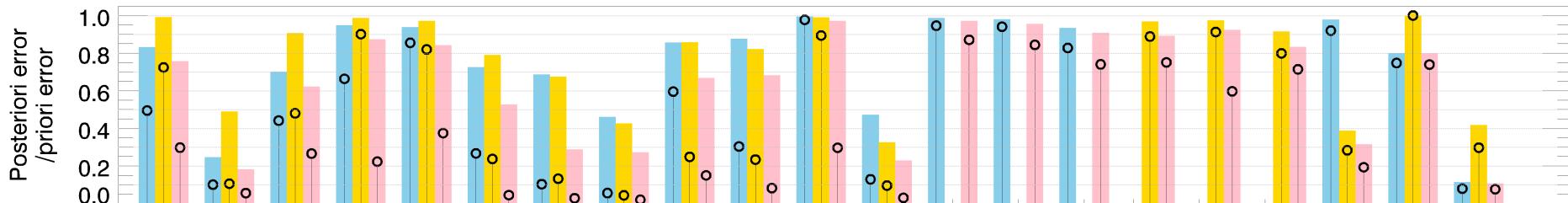
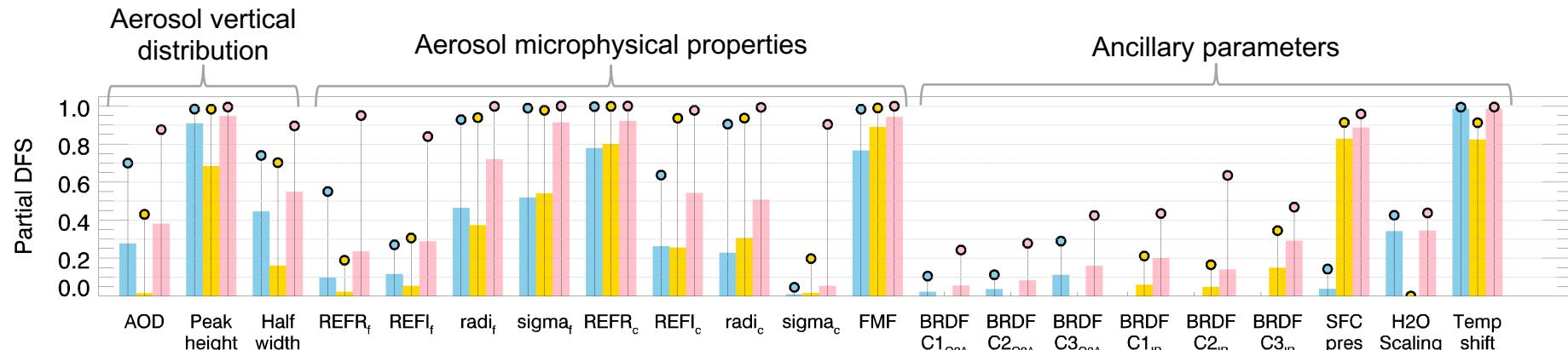
- Radiance-only



Estimated DFS and retrieval uncertainties

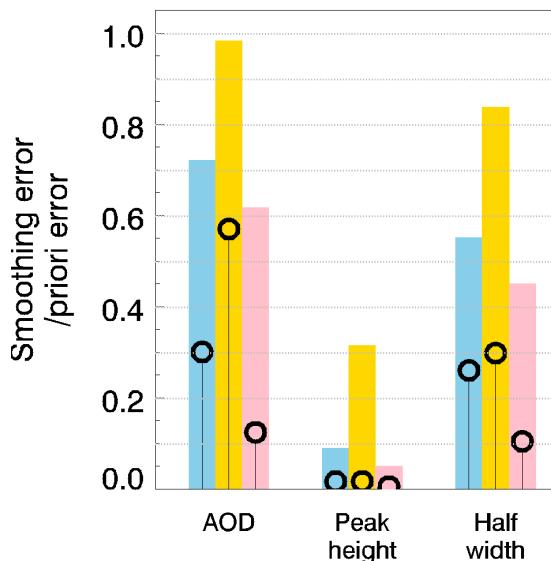
- FWHM 1.0 cm⁻¹
- SNR 300
- 50 different aerosol loading scenarios

Total DFS	O ₂ A	IR	O ₂ A+IR
Num. retrieval parameters	18	18	21
Radiance	6.4	6.0	10.2
Radiance + Polarization	10.8	11.1	16.3

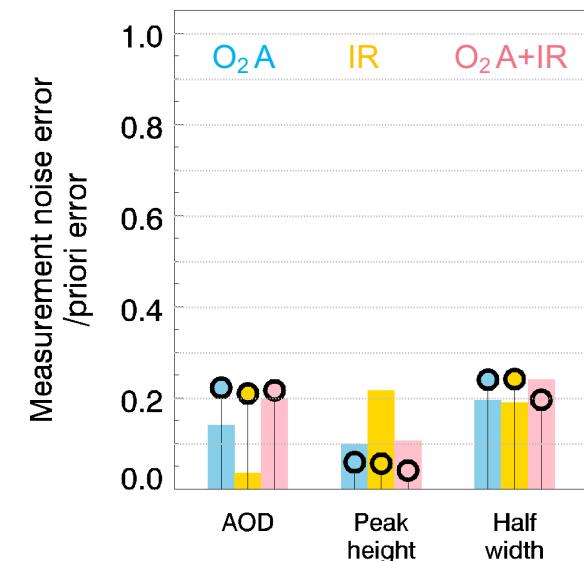


Estimated attribution of retrieval uncertainty

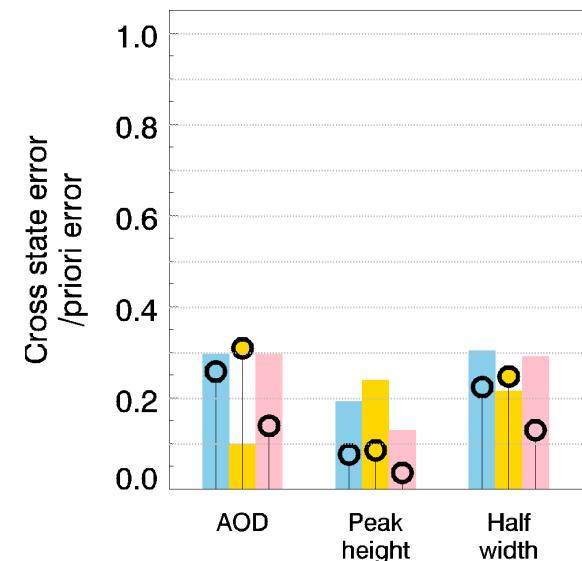
Smoothing error



Measurement error



Cross-state error
(or interferent error)



Estimated impacts of calibration uncertainty on aerosol retrievals

- $\Delta\hat{x} = G\Delta y$
- Scenario
 - CLARS geometry
 - O₂ A-band only
 - Joint radiance/polarization

Calibration uncertainty		Estimated retrieval bias		
I	DoLP	AOD 0.3	Peak height 0.6 km	Half width 0.6 km
2%	0.005 (0.5%)	3.2%	1.2%	1.7%
5%	0.02 (2%)	9.5%	4.2%	3.6%

